"I Did Not Know . . . Any Danger Was Attached"

Safety Consciousness in the Early American Ice and Refrigeration Industries

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On the afternoon of 10 July 1893, Captain James Fitzpatrick of the Chicago Fire Department received a call to put out a fire in the ice plant at the World's Columbian Exposition. Fitzpatrick had gone to fight small blazes in the same building twice before, both caused by a design defect in the plant's smokestack. To obscure the stack from the view of fairgoers, the architect had encased it in a 225-foot wooden tower that stood five feet taller than the stack itself. The architect's plan had called for an iron "thimble" to be installed atop the smokestack to prevent particles and debris from igniting the tower. But the Hercules Iron Works of Aurora, Illinois, the company that constructed the fair's ice-making machinery and the building that contained it, never installed the thimble. The fire of 10 July started when flames from soft, greasy-burning coal used to fire the boiler below ignited soot in the upper reaches of the smokestack.[1]

When Fitzpatrick arrived at the scene, he assumed that the conflagration resembled the ones he had faced earlier. As he had done on these other occasions, he ordered his men to use their ladders to climb the outside of the tower and fight the fire where it had started. "We'll put this blaze out in a minute," he said at the time.[2] But this time the fire had already spread

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1. On the Chicago world's fair fire of 10 July, see accounts published in the *Chicago Record, Chicago Inter Ocean, Chicago Daily News, Chicago Evening Post,* and *Chicago Tribune* between 10 July and 20 July 1893.
2. "They Do Not Agree," *Chicago Inter Ocean*, 18 July 1893.

from the top of the smokestack to the building below. Fitzpatrick and his men alighted onto a balcony approximately fifteen feet below the flames. Shortly thereafter, there was an explosion in the building below them, sealing off their escape path. According to one eyewitness:

> [I]mmediate confusion followed among those on the balcony. Two men at once jumped into open space, two were lost on the west side of the tower, and the balance of the frightened human beings rushed to the north side of the tower and huddled together, all-fearful of the oncoming flames and apparently realizing that they were now between two deaths—that of being burned or crushed. Desperation probably caused them to seek the latter, and out into the air in rapid succession shot a half-dozen human beings, whirling and circling over and over. When these poor men struck the flat roof eight feet below they bounded back into the air and fell back again to struggle with death. At last but two men were left surrounded within five feet on all sides with fierce flames. It either was to jump quick or death from fire. One grabbed a rope, started slowly down, passed through two sheets, and then the rope burned in two and the hanging men fell to the roof, bounded into the air a confused mass of arms and legs, and again fell back. As the next man took hold of the rope the four walls separated like melting crust and he was whirled into the burning tower, while the east wall, covered with fire, fell on the man who jumped before him.
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> The sight fascinated while it sickened, and the situation was made more awful from the fact that thousands of Fair visitors were looking on, and as each person tumbled to a horrible death a simultaneous murmur of horror escaped from throats for fully a half mile in every direction.[3]

The blaze killed seventeen people, including Captain Fitzpatrick and eight other firemen (fig. 1). It left nineteen people, including five firemen, seriously injured.

The ensuing investigation focused on the smokestack. Ultimate responsibility for this fatal flaw was never determined.[4] However, the investigation

3. Ibid.

4. Benevolent Association of the Paid Firemen of Chicago, *A Synoptical History of the Chicago Fire Department* (Chicago, 1908), 75. A coroner's jury did refer two officials from the Hercules Iron Works, one world's fair official responsible for fire safety, and one Chicago Fire Department officer to a grand jury to be investigated for criminal negligence. No charges were ever brought. The fact that each man could be judged partly responsible probably saved them all from prosecution. The officials of the Hercules Iron Works should have installed the thimble on the smokestack. The world's fair official should have forced them to do so, and the fire department (Captain Fitzpatrick in particular) should have checked to see if the fire had spread to the bottom of the smokestack before sending men up into the tower. Even though it was not legally responsible for the

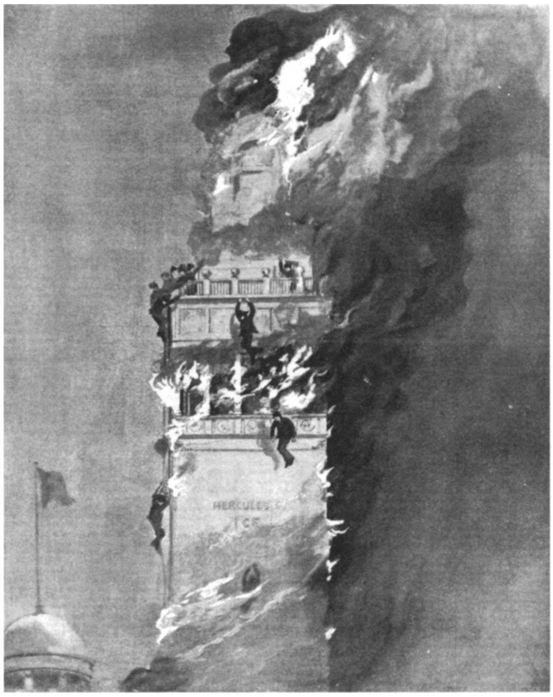

FIG. 1 Firemen jump from the top of the Cold Storage Palace at the World's Columbian Exposition after it exploded. (*Scientific American*, 22 July 1893. Courtesy of the Library of Congress.)

did indicate that, had the building not exploded, the firemen would not have been trapped on the balcony and could have put the fire out easily, just as they had twice before. What, then, caused the explosion? The answer to that question was "ammonia in the refrigeration system," which when it caught fire caused a "deafening explosion of the ammonia pipes."[5] When ignited, gaseous ammonia mixed with air at concentrations of between 16 and 25 percent can lead to deflagration, an intense shock wave that resembles an explosion. A mixture of ammonia and oil can deflagrate at an even broader range of concentrations.[6] And superheated ammonia can also break down into nitrogen and highly flammable hydrogen.

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fire, the Hercules Iron Works lost about $250,000 because it had little insurance on the building. This loss led to the company being reorganized. By July 1896, it was in receivership. See *Ice and Refrigeration* 5 (August 1893): 91 and *Ice and Refrigeration* 11 (July 1896): 36d.

5. "Fire in All Its Fury," *Chicago Inter Ocean*, 11 July 1893.

6. United States Environmental Protection Agency, "Hazards of Ammonia Refrigeration at Ammonia Refrigeration Facilities (Update)," EPA 550-F-01-009, August 2001, 2.

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Nearly all refrigeration machines, now as in the nineteenth century, operate by the same three processes: compression, evaporation, and expansion of the refrigerant.[7] But if the basic process behind mechanical refrigeration has not changed much since the early days of the industry, the attention that manufacturers and operators pay to safety has increased dramatically.

Mechanical ice production and commercial cold storage began during the late nineteenth century in the United States, but for several decades—the period between 1880 and 1930—technological and scientific understanding of refrigeration remained inchoate.[8] Most American manufacturers of refrigeration equipment used ammonia as the refrigerant because its high latent heat had the greatest potential energy available to produce cold. Although some manufacturers of ammonia-compression refrigeration equipment acknowledged the risk of fire, they downplayed it. In contrast, those European manufacturers who employed competing technologies stressed safety because it was a significant advantage of their systems. It took repeated tragedies (not all as deadly as the fire at the Columbian Exposition) to make ice-plant operators, cold-storage warehouse owners, and the general public fully aware of the dangers of ammonia-compression equipment. Even then, only pressure from municipal governments and consumers forced the industry to take all necessary safety precautions.

Some people involved in the ice and refrigeration industries recognized the risks associated with using ammonia-compression equipment early on.

7. In the first step of artificial cooling, the refrigerant in its gaseous state is compressed. This generates heat in proportion to the amount of pressure. The hot, compressed gas is then forced through a condenser of coiled pipes submerged in cold water until enough heat is drawn off to liquefy the refrigerant. The liquefied refrigerant is drawn through an expansion valve. The expansion valve lowers the pressure to a point at which the refrigerant returns to a gaseous state. This liquid-to-gas transformation requires heat. Since the condenser absorbed the heat from the last state of change, the liquid refrigerant draws the heat for its retransformation into a gas from the surrounding area, lowering the temperature. Owing to the expense of refrigerants, all refrigerating machines operated as closed systems—that is, the same material was put through the gas-to-liquid-to-gas cycle over and over.

8. In studying this period for evidence of gradual change in the industry's attitude toward safety, I have drawn on four sources; the journal *Ice and Refrigeration*, founded by the Nickerson and Collins Company of Chicago in 1892, which was the most important trade publication for refrigeration-equipment manufacturers, ice-machine and cold-storage operators, and natural-ice dealers (and is still published, under the name *Industrial Refrigeration*); accounts of refrigeration developments in other contemporary media; trade catalogs put out by refrigeration-equipment manufacturers, particularly interesting because they often attempted to educate buyers about the fundamentals of refrigeration technology; and retrospective assessments by refrigeration-industry professionals. There are very few secondary sources available on the American ice and refrigeration industries, except those written by refrigerating engineers. The last secondary work by a professional historian was Oscar Edward Anderson Jr., *Refrigeration in America* (Princeton, N.J., 1953).

"It is not necessary to call the attention of the ice machine operator to the fact that ammonia will explode," wrote the editors of the trade journal *Ice and Refrigeration* in 1894. "Explosions of this substance are now of not an infrequent occurrence; and as the number of ice-making and refrigeration plants increases from month to month, it is quite possible that the number of reported explosions may increase also."[9] Yet this knowledge was not disseminated among the men who owned and operated such facilities until much later, after many damaging fires and more than a few fatalities (fig. 2).[10] The Hercules Iron Works, which owned the building and refrigeration machinery at the Columbian Exposition, bought less than six thousand dollars of insurance coverage, though the machinery and building were valued at two hundred thousand dollars. This suggests that J. B. Skinner, the manager of the Hercules Iron Works, was sincere, if tragically mistaken, when he told the *Chicago Record* that "Ammonia was used for freezing, but there was nothing about it that would explode." Similarly, the president of the Chicago world's fair told a reporter from the same paper the same day, "I did not know until I was told to-day that any danger was attached to the use of chemicals in the refrigerating process."[11] Even the people who understood that there were risks in using ammonia-compression equipment did not recognize the magnitude of the danger for years, and as late as the 1910s some experts still doubted whether ammonia could actually explode. As technical understanding improved over the next four decades, the people who ran ice and refrigeration facilities became more safety conscious.

The tendency of refrigeration-equipment manufacturers to deemphasize the risks associated with ammonia-compression technology helps explain why the operators of the equipment did not initially appreciate the danger they faced. For example, Carl Linde of the Munich Polytechnic College, the inventor of ammonia-compression technology, claimed that his refrigeration machine was "unaccompanied by any danger."[12] American firms made similar claims. Sales literature from the Frick Company of Pennsylvania in 1888 asserted that ammonia "is not explosive or dangerous."[13] A

9. *Ice and Refrigeration* 7 (October 1894): 243.

10. In 1903, the Chronicle Company of New York published a compendium of twenty-eight years of fire-loss statistics in the United States, arranged by type of building. It listed 159 fires in artificial-ice plants between 1875 and 1902. At the end of this period, there were only 787 such establishments in the entire country. *The Chronicle of Fire Tables for 1903* (New York, 1903), 273, 461, 464. The 1903 compendium appears to be the last published compilation of fire statistics in which refrigeration facilities have their own separate category. See John E. Starr, "Accidents in Refrigerating Plants," *Journal of the American Society of Refrigerating Engineers* 3 (March 1917): 5.

11. "Confession of Judgement," and "Fair Officials Overwhelmed," *Chicago Record*, 11 July 1893.

12. *Engineer* 50 (1880): 211, clipping from Roy Eillers Collection, National Museum of American History, Washington, D.C. (hereinafter NMAH).

13. Frick Company, *Eclipse Refrigerating Machinery* (n.p., 1888), Refrigeration Pamphlet Collection, NMAH, 9.

FIG. 2 Ruins of the Stone Lake Ice Company at Cincinnati, Ohio. Reports of catastrophic fires at ice and refrigeration plants were common in the trade press around the turn of the twentieth century. (*Ice and Refrigeration* 18 [June 1900]: 512. Courtesy of the Hagley Museum and Library.)

pamphlet produced by the De La Vergne Refrigerating Machine Company of New York City in 1890 mentioned ammonia's "great stability, its non-inflammability and non-explosiveness."[14] This suggests that customers were concerned about the safety of the ammonia-compression process, but not enough to give up its perceived advantages.

It would have been easier to act upon impulses toward safety consciousness if it had been clear exactly where the danger lay. In the early days

14. De La Vergne Refrigerating Machine Company, *Processes and Apparatus of the De La Vergne Refrigerating Machine Company of New York* (New York, 1890), NMAH, 15–16.

of the industry neither manufacturers nor their customers nor refrigeration engineers understood the circumstances under which ammonia exploded. As the engineer R. L. Shipman told a meeting of his colleagues in 1905, "I have made some investigations myself [with regard to whether ammonia can explode] and am sorry to say, so far as I am concerned, I am not capable of deciding one way or the other."[15] As late as 1914 the insurance inspector William Tallamy could write, in a guide for others in his field: "Some authorities claim that ammonia gas when properly mixed with air will explode, while others claim the reverse. At any rate such a mixture in a refrigerating establishment is a very remote possibility."[16] Without proof of a relationship between ammonia and explosions, let alone of cause and effect, safety measures developed slowly, in reaction to tragedies rather than in anticipation of them.

But as users of refrigeration technology accumulated more information about its dangers, they became increasingly risk averse. Safety consciousness began with the operators of ammonia-compression equipment and gradually spread to manufacturers.[17] The process depended more on cultural than economic factors; perception was the key. Though the risk of fire had existed from the earliest days of the industry, users' comprehension of it developed only gradually, as did the technological knowledge needed to mitigate that risk. Even insurance companies, including some created specifically to protect companies in the ice and refrigeration industries, did not require the use of every available method to diminish the risk of ammonia explosions, because they did not adequately understand how or why they occurred. But as technical knowledge of refrigeration systems improved, safety measures became more effective.

Increased understanding of the risks inherent in ammonia-compression refrigeration brought increased government regulation at the state and local level. The changing makeup of the refrigeration-technology market accelerated this trend. By the 1920s, when the general public became consumers of refrigeration technology and the home refrigerator and air conditioner became the focal points of the industry, safety consciousness began to drive the development of new product lines. Because domestic con-

15. "Discussion of the Topic—Is Ammonia Gas Inflammable?" *Transactions of the American Society of Refrigerating Engineers* 1 (1905): 175.

16. William J. Tallamy, "Refrigeration," Live Articles on Special Hazards, No. 5, *Weekly Underwriter* (1913–1914): 80. This is a bound series of articles reprinted from the monthly fire insurance supplement of the *Weekly Underwriter*, designed to give insurance adjusters added guidance regarding risks in industries they did not fully understand.

17. By "safety consciousness," I mean that operators and manufacturers came to realize that accidents did not have to be routine matters and could be prevented by taking precautions. This definition is inspired by Mark Aldrich, *Safety First: Technology, Labor, and Business in the Building of American Work Safety, 1870–1939* (Baltimore, 1997), 2–3.

sumers would not tolerate the risks associated with ammonia-compression technology, such equipment came to be confined to large industrial plants.

Societies grow more risk averse as the degree of danger their members perceive rises: risk is less acceptable if consumers believe that they are being placed in mortal peril while businesses reap financial benefits. Because safety lapses depend upon human behavior, chance, or "acts of God" (as many insurance policies put it), anthropologists who study how societies assess risk stress the role of cultural forces in decisions to accept a given danger.[18] A path for the historical study of how American society in particular has evaluated risk was blazed by John Burke's 1965 examination of boiler explosions on steamboats during the early nineteenth century.[19] Burke noted that boiler manufacturers of that era often skimped on materials, resulting in weaker-walled boilers more prone to burst, even as operators routinely overloaded them to increase speed. For several decades, in the face of public outrage and a technically definitive analysis of boiler explosions by the Franklin Institute, Congress refused to act because most legislators did not think they had the power to regulate commerce. Finally, in 1852, Congress passed the nation's first substantive regulation of a technological practice. The death toll on the nation's rivers dropped precipitously.

A number of more recent historical works have tried to assess how cultural factors affected the perception of risk in specific industries as they grappled with technological change. For example, Sara Wermiel has described changing attitudes toward fire safety that gradually caused expensive fireproof-building technology to be widely adopted. This occurred not only because of changes in economic circumstances but also because of a complex interaction between improvements in technology, new attitudes on the part of of state and local governments, and various economic actors' changing perception of risk.[20] Mark Aldrich compares the safety situation on American and British railroads during the late nineteenth century and finds the risks higher in the United States in large part due to the lack of "active interest of railroad management in work safety." Laws requiring the use of safety equipment were ineffective as long as the culture of American railways remained hostile to its proper use.[21]

Unlike steamboat owners, who staunchly resisted regulation, operators of ammonia-refrigeration plants did instigate safety measures. But a genuinely new culture of safety was only ushered in after 1920, as new key play-

18. See, for example, Mary Douglas and Aaron Wildavsky, *Risk and Culture: An Essay on the Selection of Technology and Environmental Danger* (Berkeley, Calif., 1982), and Mary Douglas, *Risk and Blame: Essays in Cultural Theory* (London, 1992).

19. John G. Burke, "Bursting Boilers and the Federal Power," *Technology and Culture* 7 (1966): 1–23.

20. Sara E. Wermiel, *The Fireproof Building: Technology and Public Safety in the Nineteenth-Century American City* (Baltimore, 2000).

21. Aldrich, 39–40.

ers emerged, oriented toward mass markets and operating in a climate characterized by rising insurance costs and increasing local and state regulation; by that time, large-scale ice plants and cold-storage warehouses had ceased to be the dominant focus of the industry.

* * *

Mechanical refrigeration was the result of discoveries by numerous individuals over many decades in various countries.[22] However, the pivotal moment was Carl Linde's development in 1877 of a commercially viable system that used anhydrous ammonia as the refrigerant.[23] Ammonia-compression refrigeration created an enormous amount of cold at a reasonable cost, and it remained the technology of choice in Germany and the United States for decades. Linde sold U.S. manufacturing rights to the Fred C. Wolfe Company of Chicago in 1881. By 1899, 74 percent of American ice manufacturers used machines similar to the one Linde invented. By 1909, that number had grown to 86 percent.[24] The Linde system dominated the American and German industries at a time when the number of ice machines expanded significantly. The number of cold-storage facilities, which also tended to use ammonia-compression machinery, rose sharply during this period in the United States as well.

Ammonia could theoretically absorb more heat than any other common refrigerant known at the turn of the century, though in practice ammonia-compression refrigeration technology was not perfectly efficient.[25] For example, cold-storage warehouses used an indirect system of refrigeration in which compressed ammonia chilled pipes full of salt brine that in turn chilled the cold-storage area because an ammonia leak could damage food and other organic matter. The additional heat transfer made the system less efficient; corrosion caused by the brine meant that the pipes had to be replaced every six years or so, which made it costly as well.[26] Other causes of decreased efficiency included leakage around pistons and valves and the buildup of oil inside the machine.[27]

Owners of ice plants and cold-storage warehouses bought into the

22. See, for example, Roger Thévenot, *A History of Refrigeration Throughout the World* (Paris, 1979), 27–65.

23. "Anhydrous" means not mixed with water. Household ammonia is mixed with water to stabilize it so that it will not explode.

24. Anderson (n. 8 above), 105.

25. As Hans-Liudger Dienel observes, "Linde's fundamental decision in favour of the compression refrigeration machine was motivated by thermodynamic considerations, but it was based on premises that thermodynamics later repudiated"; Hans-Liudger Dienel, *Linde: History of a Technology Corporation, 1879–2004* (New York, 2004), 247.

26. Louis K. Doelling, "Twenty-Five Years Evolution of Refrigeration," *Ice and Refrigeration* 51 (November 1916): 159.

27. Louis M. Schmidt, *Artificial Ice-Making and Refrigeration* (Philadelphia, 1900), 11.

ammonia-compression system because they were not technologically sophisticated enough to judge manufacturers' promises of high production capacities critically. As the journal *Cold Storage* explained: "A man who goes into business will seldom but have to attend strictly to the part of business which brings in the money. In giving all of his time to this he seldom feels inclined to spend his time in reading of the science, and even if he wanted to he would not be able if he had not received the necessary education."[28] Buyers invested in refrigeration technology, a decision with significant long-term consequences for the future of their businesses, without understanding the risks involved.

The industry's embrace of ammonia-compression technology seems surprising because a safer and equally efficient alternative existed by 1890. After experimenting with a variety of materials and designs, Franz Windhausen of Brunswick, Germany, gradually developed a system that used carbon dioxide as the refrigerant; the first commercially viable examples appeared in 1886.[29] Though these were similar in operation to ammonia compressors, carbon dioxide had to be subjected to much higher pressure. It was difficult to solder pipe well enough to withstand such high pressure, so it took time for carbon dioxide to develop into a practical alternative to ammonia-compression systems; not until the late 1880s did engineers at the J. and E. Hall company in London work out a solution to that problem.[30] In the meantime, the American refrigeration market closed around ammonia compression. By the time carbon-dioxide refrigeration matched that technology in quality, American makers of ammonia-compression equipment already had a support infrastructure for their customers in place. Companies that had only recently invested in expensive refrigeration machinery were unlikely to replace it.

Nevertheless, carbon-dioxide technology had many clear advantages. Its efficiency matched that of ammonia systems.[31] But it cost less, and was nonflammable and nonirritating. Granted, high operating pressures meant that leaks were a risk, but copper pipe helped solve this problem, because it was stronger than steel and would not rust. And because carbon-dioxide compressors did operate under high pressure, they came equipped with pressure-release safety valves to prevent explosions. And while ammonia gas is toxic, carbon dioxide can only kill by preventing air from reaching the lungs, a circumstance that safety equipment designed to control release of the gas could prevent.

However, manufacturers and consumers in countries where ammonia-compression technology was well established either did not yet understand

28. "Cold," *Cold Storage* 3 (April 1900): 84.

29. Thévenot (n. 22 above), 452.

30. Harry Miller, *Halls of Dartford, 1785–1985* (London, 1985), 71–72.

31. J. C. Goosman, *The Carbonic Acid Industry* (Chicago, 1906), 149.

these advantages or they did not care about them. In *Machines Are Frozen Spirit*, Mikael Hård discusses the "scientification" of the refrigeration industry in Germany in the 1880s, by which he means that consumers picked their machines on the basis of quantifiable values, such as capacity or efficiency, rather than abstract ones, such as safety. According to Hård, "The emphasis on practically rational factors like degree of efficiency meant that poisonous ammonia outpaced less efficient but fairly harmless carbon dioxide as a refrigerant in vapor compression machinery."[32] German brewers, the chief consumers of ammonia-based equipment, bought it because during the 1880s it did surpass its competitors in terms of efficiency. The close relationship between Carl Linde and the brewing industry strengthened this temporary advantage, and ammonia systems dominated the German market long after their efficiency advantage had disappeared.[33] American brewers invested heavily in ammonia-compression systems for the same reason, and brewers were the main buyers in the United States through the mid-1880s.[34] As the American refrigeration market expanded from its original brewery base to ice manufacturers and cold-storage warehouses, so did the dominant refrigeration technology.[35]

American manufacturers and their customers proved even more production oriented than the Germans. "What bothered us most was the production of any kind of cold in regular quantities," remembered Thomas Shipley of the York Company. "What we were after was cold weather and as much of it as we could get."[36] Owners of artificial ice companies and cold-storage warehouses scattered across the United States shared these priorities. Writing in 1900, the engineer M. C. Bersch claimed that these purchasers would pick a larger machine over a smaller, more efficient machine of the same type "in nine cases out of ten."[37] This production-oriented mentality made carbon-dioxide refrigeration equipment a hard sell. By the turn of the century, firms that manufactured such equipment in the United States, like Kroeschell Brothers of Chicago, had begun to use safety rather

32. Mikael Hård, *Machines Are Frozen Spirit* (Boulder, Colo., 1994), 235.

33. Hans-Liudger Dienel, *Ingenieure zwischen Hochschule und Industrie: Kältetechnik in Deutschland und Amerika, 1870–1930* (Göttingen, Germany, 1995), 95–96, 113–14. I am indebted to Henry Wend for his unpublished translation of pertinent sections of Dienel's 1995 work.

34. Barry Donaldson and Bernard Nagengast, *Heat and Cold: Mastering the Great Indoors* (Atlanta, 1994), 136.

35. The process is exemplified by the De La Vergne Company. Originally a brewer, John C. De La Vergne began manufacturing ammonia-compression equipment in 1881 for his brewery. Ten years later when the boom hit he began to construct and equip ice-production plants under contract to independent operators. Anderson (n. 8 above), 94.

36. Thomas Shipley, "Recollections of the Ice Machine Industry," *Ice and Refrigeration* 51 (November 1916): 163.

37. M. C. Bersch, "To Prove Efficiency of Ice Machines without a Trial," *Ice and Refrigeration* 18 (April 1900): 331.

than capacity to sell their product. "Violent explosions are of frequent occurrence with ammonia ice making and refrigeration plants," read the company's 1901 catalog, which featured a collection of newspaper stories describing ammonia disasters.[38] This tactic had limited success. Niche markets—"Ships, restaurants, hotels, and other places where safety was particularly important"—used carbon-dioxide technology, but few others did.[39]

These manufacturers' sales pitches fell on deaf ears because of the general lack of safety consciousness in the early American refrigeration industry. William Nottberg, writing in *Ice and Refrigeration* in 1906, berated American manufacturers for making "no provision to protect the machine, pipes, works and fittings against an undue pressure—pressures which reach the danger point in less than ten revolutions of the machine. Who would think of buying a boiler without a safety valve? Ask that question and you get as an answer, 'Get an engineer who will keep his eyes open,' or 'Our machine, pipes and fittings will stand a pressure which will stop the machines before they burst.'"[40] In 1917, the refrigerating engineer T. O. Vilter recalled that "in the early days great carelessness prevailed in the installation of refrigerating machinery." He told of checking on an installation where a competitor had underbid him and finding "2 by 4s nailed against the joists with a couple of spikes and other spikes driven at an angle into the 2 by 4s. . . . Now that surely was not putting up ammonia pipe in the proper manner. We do not dare to do such work, because we do not want accidents."[41] In 1897, the editors of *Ice and Refrigeration* recommended "eternal vigilance" by employees as the solution for safety problems, conveniently placing the responsibility for any mishap squarely on the workers.[42]

In contrast, safety concerns did influence the development of refrigeration technology in Great Britain, where carbon-dioxide machines dominated. Hall's improvements to Windhausen's carbon-dioxide patent made the company one of the largest British manufacturers of refrigeration equipment. Everard Hesketh, head of the company at this time, "played for safety," writes Harry Miller in his history of the firm. During one of its early installations, a pipe in the system burst because of a mechanical failure. Hesketh later recalled: "The pipe was literally blown to ribbons and had it not been for the sides of the water tank surrounding the compressor . . . my head, which was only a yard away, would have been the target for some of the pieces." Because of this accident, the firm pioneered the use of the auto-

38. Kroeschell Brothers Ice Machine Company, *Modern Refrigerating and Ice Making Machinery*, 1901, NMAH, 60.

39. Anderson (n. 8 above), 97.

40. William Nottberg, "Some Faults in Ice Machines," *Ice and Refrigeration* 31 (July 1906): 1.

41. Recollections of T. O. Vilter, *Journal of the American Society of Refrigerating Engineers* 4 (July 1917): 32.

42. "Ammonia Accidents," *Ice and Refrigeration* 13 (August 1897): 109.

matic safety valve, which shut down the system if pressure built up too high.[43] This innovation greatly spurred the spread of carbon-dioxide compression technology outside the United States.

Those connected with the ice and refrigeration industries often claimed that refrigeration equipment posed no greater risks than other industrial machinery, but the high insurance rates they paid undermined their argument. "Contrary to the general idea," one insurance agent told *Ice and Refrigeration* in 1896, "insurance companies would rather take a risk on a powder magazine or a powder manufactory than on an ice [plant]. . . . [M]any people think such places will not burn. They do burn, however, and the result is the insurance companies charge the highest risk."[44] In response to high rates, ice manufacturers organized mutual insurance companies. Member firms contributed annual premiums to an insurance pool, with the premium amount based on a firm's size relative to the others involved. In exchange for the ability to take money from the pool in the event of fire, each firm agreed to an impartial inspection and further agreed to make changes recommended to lower its risk. At the end of the year, the insurance company returned the remainder of the premium pool to the member firms. In 1904, the Ice Manufacturers Exchange, the largest such arrangement in the industry, saved its members approximately 50 percent in premiums.[45] In short, facing higher insurance costs, companies reformed their insurance coverage and maintenance practices rather than invest in a radically different technology to enhance safety.

Lacking a thorough understanding of the risks, ice-plant and cold-storage operators could not judge the potential costs of accidents, and many therefore did not take fairly simple measures that might stop catastrophic fires. The list of recommendations by the Middle States Ice Producers' Exchange, a mutual insurance company, following a fire at a plant belonging to one of its members in 1908, is illustrative: install a fire door between the boiler house and the engine room; install a metallic collar around the smokestack to protect the roof; place a metal waste can in the engine room; agree not to keep more than one extra drum of ammonia on the premises, except when charging the plant.[46] Such steps undoubtedly helped reduce the risk of fire, but the industry could have done much more. A summary of a National Fire Protection Association report in *Ice and Refrigeration* in 1907 called attention "to a number of the more recent arrangements in the way of check valves, automatic shut-offs, etc., that minimize the possibility of accidents either from the use of oil or from the gas."[47] The inventor of a

43. Miller (n. 30 above), 71–72.

44. *Ice and Refrigeration* 11 (August 1896): 101.

45. Bruce Dodson, "Mr. Dodson's Address on Insurance," *Ice and Refrigeration* 26 (April 1904): 211.

46. "Reduced Insurance Rates," *Ice and Refrigeration* 35 (September 1908): 117.

47. "Fire Hazards in Refrigerating Plants," *Ice and Refrigeration* 32 (May 1907): 327.

new automatic shutoff device claimed in 1910 that it made "explosion, or bursting the cylinder head, impossible."[48] Yet insurance companies did not require the installation of such devices, and it appears that most firms did not install them of their own accord until after government became more involved in regulating these industries.[49]

That increased involvement occurred as a result of a number of high-profile refrigeration disasters, of which a series of fires during 1915 in the ice plants and cold-storage warehouses of New York City was the most important. The worst of these occurred on 26 April at the Manhattan Refrigerating Company; despite safety equipment installed in the plant, fifteen people were injured and the surrounding neighborhood filled with ammonia fumes.[50] In response, the New York Board of Fire Underwriters began to pressure the city's Bureau of Fire Prevention to establish new safety regulations for ice plants and cold-storage warehouses.[51] The State of Massachusetts adopted the first safety code for refrigerating plants in 1914, but the New York City code had more influence over other jurisdictions. Though the city consulted with the American Society of Refrigerating Engineers, the ordinance eventually incorporated tougher requirements than the engineers had preferred, such as emergency pipes to prevent a buildup of ammonia in a machine room. The ordinance also banned open flames, arc lights, and direct openings to the boiler room in any area containing ammonia-refrigeration equipment. Eventually, thirty other large cities and several states passed similar measures.[52]

But the industry itself remained recalcitrant. After the New York fires, *Ice and Refrigeration*, which depended upon manufacturers for much of its advertising, editorialized that "it would be unwise to assume ammonia is the guilty agent, and place it under needless restrictions, instead of placing such restriction, where it should be placed, namely on the thing that actually caused the accident."[53] Change would come slowly and would not be complete until the general public, rather than small businesses, became the industry's main customer.

Despite the existence of safety devices and the passage of laws such as New York's, fires and explosions continued. As late as 1920 a fire insurance

48. "A New Safety Device," *Ice and Refrigeration* 39 (November 1910): 232.

49. Writing of a New York City ordinance in a 1934 article looking back on early safety efforts, the engineer Harry D. Edwards commented: "As you look over this code today it is striking for the rather negative aspect of its provisions. I mean by that, it devotes chief attention to setting up brand-new emergency attachments, as if for a plant where no safety provisions had previously been used, and where no parts of the system had been designed to any standard requirements. Such indeed was the case." See "The Refrigeration Safety Code," *Refrigerating Engineering* 28 (November 1934): 231.

50. "Ammonia Explosion Injures Fifteen Workmen," *New York Times*, 27 April 1915.

51. "Ammonia Explosions," *Ice and Refrigeration* 49 (August 1915): 76.

52. Edwards, 231.

53. "Ammonia Explosions," *Ice and Refrigeration* 49 (August 1915): 76.

underwriting guide observed that explosions remained a frequent occurrence in ammonia-refrigeration plants.[54] Gradually the public became aware of the danger. As the editors of *Ice and Refrigeration* wrote in 1924: "Whenever an accident occurs in an ice plant, the newspapers immediately attribute it to an ammonia explosion."[55] Many of those who continued to use that technology also continued to argue that ammonia was perfectly safe, but the public had ceased to agree. This created an opportunity for champions of new technology. While ice and refrigeration firms mostly ignored the public's concerns, companies looking to develop other markets started searching for a viable alternative to ammonia. As a 1926 report from one chemical laboratory explained, "in recent years frequent disasters in industrial plants operating with [ammonia] have created a country-wide resentment against its use in residences or other inhabited buildings."[56]

By the 1920s, alternatives to ammonia refrigeration had been actively explored for three decades. Linde began experimenting with new designs during the 1890s.[57] By 1916, Fred Wittenmeier of the Kroeschell Brothers Company reported "that a number of refrigerating machine manufacturers who formerly built ammonia machines and apparatus exclusively are now also building CO_2 refrigerating machines."[58] The most important new use for refrigeration technology in the 1920s was air-conditioning. But, as Gail Cooper explains in *Air-Conditioning America*, "One of the prime technical difficulties in developing comfort air-conditioning was the safety hazard posed by the use of ammonia as a refrigerating agent."[59] Many of the first air-conditioning installations used carbon dioxide, starting with work by the Kroeschell Brothers Company in 1907. The earliest air conditioners were large machines placed in structures such as movie theaters and factories, where, as with earlier ship or hotel installations, safety concerns dictated the choice of refrigerant. But because it required such high compression, which necessitated heavy equipment, carbon-dioxide technology was unsuitable for use in the home. Size and weight were especially important factors in window air-conditioning units, which began to appear after 1930.

54. Charles C. Dominge and Walter O. Lincoln, *Fire Insurance Inspection and Underwriting* (New York, 1920), 26.

55. "Explosion Unjustly Attributed to Ammonia," *Ice and Refrigeration* 67 (October 1924): 239.

56. Research Laboratories of the Roessler and Hasslacher Chemical Company, "Methyl Chloride—A Safe Refrigerant," Technical Paper No. 26, 1926, Hagley Museum and Library, Wilmington, Del., 27.

57. In fact, its decision to experiment with carbon dioxide as a refrigerant led to the development of gas liquefaction, which soon became its core business. Dienel, *Linde* (n. 25 above), 65.

58. Fred Wittenmeier, "Development of Carbon Dioxide Refrigerating Machines," *Ice and Refrigeration* 51 (November 1916): 165.

59. Gail Cooper, *Air-Conditioning America: Engineers and the Controlled Environment, 1900–1960* (Baltimore, 1998), 89.

More important than constraints on domestic use imposed by equipment, however, were consumer fears of dangerous chemicals.[60] As early as 1918, Willis Carrier and his associates began to search for an air-conditioning refrigerant less hazardous than ammonia or sulfur dioxide, the two most common at the time.[61] Home refrigerators posed a similar problem. Early models, developed between 1915 and 1930, had a tendency to leak gas, so the use of toxic gas as a refrigerant created an obvious potential for disaster.[62] Manufacturers approached this problem with various compromises. Kelvinator, the first successful home refrigerator manufacturer, settled on sulfur dioxide for its early models, though it is a toxic gas, in part because the company did not want to use a flammable substance.[63] But the Roessler and Hasslacher Chemical Company marketed methyl chloride as a "safer" alternative to ammonia for home refrigerators in 1920 (fig. 3) despite the fact that this gas is poisonous and less identifiable by smell than sulfur dioxide.[64] Seven highly publicized deaths (and more hospitalizations) in the Chicago area because of home refrigerators that leaked methyl chloride in early 1929 threatened the future of the entire home refrigerator business.[65]

In 1928, scientists at Frigidaire, a subsidiary of General Motors, and DuPont began a joint venture to search for a safer refrigerant, under the direction of Thomas Midgely Jr. Recognizing that the public would not accept a home appliance that depended upon a dangerous substance to produce cold, the first criterion they established for an "ideal refrigerant" was that it must be "nonexplosive."[66] Their effort culminated in 1930 with the invention of Freon, the trade name for the first of a class of compounds that would be known as chlorofluorocarbons. General Motors also created a joint venture with DuPont's subsidiary Kinetic Chemicals to manufacture and market Freon and develop it for other uses.[67] Freon quickly became the substance of choice for home refrigerators, and companies like Frigidaire and General Electric used their knowledge of refrigeration technology to enter the home air-conditioning market during the 1930s.[68]

Although Freon is theoretically nearly as efficient a refrigerant as am-

60. Ibid., 114.

61. Realto E. Cherne, "Developments in Refrigeration as Applied to Air Conditioning," *Ice and Refrigeration* 101 (July 1941): 28–29.

62. Donaldson and Nagengast (n. 34 above), 207.

63. Cooper, 122.

64. Research Laboratories of the Roessler and Hasslacher Chemical Company (n. 56 above), 3, 29.

65. "Fatal Results of Refrigerator Leaks," *Ice and Refrigeration* 77 (July 1929): 38.

66. E. I. du Pont De Nemours and Company, *Freon: Safe Refrigerants and Propellants* (n.p., 1950), Hagley Museum and Library, 2.

67. David A. Hounshell and John Kenly Smith Jr., *Science and Corporate Strategy: Du Pont R&D, 1902–1980* (New York, 1988), 156.

68. Donaldson and Nagengast (n. 34 above), 294–95.

FIG. 3 Fear of refrigeration-related fires was so great by 1929 that the Roessler and Hasslacher Chemical Company pitched methyl chloride as a safe industrial refrigerant in part because it was "only moderately inflammable"—even though it was also an odorless deadly poison. (*Ice and Refrigeration* 77 [December 1929], 37. Courtesy of the Hagley Museum and Library.)

monia, the primary reason for its development was safety. Nevertheless, General Motors did not promote it on that basis. An internal DuPont memorandum concluded in 1931 that, for General Motors, "'Scare' advertising copy is objectionable and besides it would reflect upon several hundred thousand Frigidaires that have already been sold to the public."[69] Furthermore, because Kinetic Chemicals sold Freon to both Frigidaire and its com-

69. W. D. Humphrey, "Du Pont Refrigerants—A Comparative Study of Our Activities in this Field and of the Progress of the Industry as a Whole," Records of E. I. du Pont de Nemours and Company, ser. 2, pt. 2, box 1036, Hagley Museum and Library.

petitors, Frigidaire would not gain any advantage by invoking safety as a marketing pitch. DuPont, however, stressed Freon's safety in its advertising.[70] "A *fear consciousness* for ammonia has been instilled in the refrigerating art," wrote one engineer in 1936. "We find this consciousness aided and even abetted by some today who proclaim a new religion called Safety, in order to sell a substitute."[71]

* * *

DuPont's campaign reflected the importance of safety to consumers by the 1930s. It also reflected manufacturers' acknowledgment of ammonia's hazards. Those that put out Freon-based equipment cited safety in operation as the prime reason. The York Ice Machinery Corporation, for example, justified its decision to make Freon equipment on the grounds that it was "non-irritating, non-inflammable, non-explosive [and] non-toxic."[72] But ammonia, its use governed by new and regularly revised safety regulations, continued to be the most important industrial refrigerant, and it remains important to this day.[73] The development of consensus around safety restrictions suggests that ignorance, rather than a different perception of acceptable risk, caused the old dispute over the hazards of ammonia. Safety measures could only be effective when operators were safety conscious enough to investigate their technology and knowledgeable enough to understand it.

In *Safety First*, the only book-length study of the national safety movement during the Progressive Era, Mark Aldrich argues that "new technology reflected the efforts of individuals and businesses to increase production and cut costs under conditions in which work injuries were of little economic consequence."[74] Only when workers gained allies among the general public and in the halls of government did workplaces become safer. But looking to labor as the counterweight to the lack of concern for safety among businessmen is not appropriate for the ice and refrigeration industries. In 1909, ice plants employed an average of eight workers.[75] Less-skilled teamsters who delivered ice would not have been present in plants

70. Its slogan was "Freon: A Safe Refrigerant." See, for example, *Refrigerating Engineering* 28 (August 1934), inside back cover. The pamphlet *Freon: Safe Refrigerants and Propellants* (n. 66 above) shows that the company continued to tout the safety angle in its marketing for a long time.

71. R. T. Brizzolara, "Old and New Refrigerants," *Refrigerating Engineering* 31 (April 1936): 228. Emphasis in original.

72. York Ice Machinery Corporation, *York Refrigerating Units: Designed Expressly for Freon* (York, Pa., 1933), NMAH.

73. A. B. Pearson, "Ammonia" (paper presented to the meeting of the Institute of Refrigeration, London, November 1999), 1.

74. Aldrich (n. 17 above), 5.

75. John G. Hawes, "Manufactured Ice," in U.S. Bureau of the Census, *Census of Manufactures, 1914*, vol. 2 (Washington, D.C., 1914), 443.

long enough to have concerns over safety. Skilled refrigerating engineers would likely have been compensated for the potential risk, as labor costs were low compared to other plant expenses, especially fuel.

Although political forces acting upon the refrigeration industry contributed to the emergence of safety consciousness, equipment manufacturers found their main motivation in economic concerns. Insurance companies rather than workers provided the first impetus for change; despite the failure of most of the industry to appreciate the risks of ammonia-compression technology, insurers pressured operators to make safety improvements in their facilities. By the 1920s the nature of these economic forces had changed, and safety consciousness began to influence the development of refrigeration products. As manufacturers began to make air conditioners and home refrigerators, the most important potential injured party became the general public, not the worker, and the industry's safety consciousness grew. Now the economic consequences of accidents became determinative. Manufacturers had to build safe equipment because to do otherwise would cause consumers to vote with their pocketbooks.

Recent work on the history of air conditioners and home refrigerators illuminates the give and take that went on between manufacturers and consumers to determine the application and design of these products. In *Air-Conditioning America*, Gail Cooper notes: "Consumers can indeed buy or boycott, but they can also sabotage, regulate, cajole and demand—or simply create a pattern of usage that resembles not at all the visions of designers."[76] Shelley Nickles has called refrigerator design "part of a larger process of social interaction" that "offers insight into how new technologies were domesticated, on whose terms, and with what social consequences."[77] Manufacturers of the first home refrigerators and air conditioners knew they had to make safe products or their innovations would never find a market. Safety was an assumption.[78] It even became a marketing tool. It was not a point of contention.

Ironically, a different kind of safety concern has revived ammonia refrigeration's popularity. Since discovery of the destructive effect of chlorofluorocarbons on the ozone layer in the 1970s, ammonia's share of the world market for refrigerants has risen; it presently stands at approximately 15 per-

76. Cooper (n. 59 above), 5.

77. Shelley Nickles, "'Preserving Women': Refrigerator Design as Social Process in the 1930s," *Technology and Culture* 43 (2002): 694.

78. Ruth Schwartz Cowan stresses the role of General Electric's money and other resources in the triumph of electromechanical-compression home refrigerators over gas-powered models in the marketplace; see "How the Refrigerator Got Its Hum," in *The Social Shaping of Technology*, ed. Donald MacKenzie and Judy Wajcman (Philadelphia, 1985), 202–18. While this was certainly one factor in their success, it neglects the importance of concerns about safety in helping home refrigeration technology gain acceptance among the buying public.

cent.[79] But in contrast to the turn of the twentieth century, its use is now heavily regulated, so that the safety of workers and the general public is much greater than it was.[80] Because modern operators recognize the risks inherent in using ammonia as a refrigerant, they can mitigate most of them. Their now stringent safety protocols reflect and embody the safety consciousness that developed during the first three decades of the last century.

79. Pearson (n. 73 above), 2.

80. Douglas T. Reindl, "Safety in Ammonia Refrigeration," in *Introduction to Ammonia Refrigeration Systems*, pamphlet prepared for refrigeration seminar, Department of Engineering Professional Development, University of Wisconsin—Madison, 5–7 March 2003, 64–65.